# Detector R&D Opportunities for the Future

# $e^+e^-$ Linear Collider

Slawek Tkaczyk, Fermilab

Aspen 2004 Winter Conference on Particle Physics

- Physics Expectations
- Linear Collider Detector R&D
  - Interaction Region
  - Vertexing and Tracking
  - Calorimetry
- North American R&D Projects

# World Wide Study of Physics and Detectors for Future LC

- **Ongoing studies of physics and detectors carried in Europe, America and Asia with $\approx$ 2 regional meetings to report progress and coordinate local efforts. (Additional organization for the accelerator activities.)**
- **The World Wide Study fosters working relations between participants of the regional studies by organizing regularly the Linear Collider Workshops ( next in Paris, April 2004).**
- **Many new theoretical ideas explored and large number of final states in the $e^+e^-$ collisions and other beam options simulated.**
- **Physics case for high energy Linear Collider has been well developed and articulated in many written documents or reports:** *LCWS proceedings, ECFA-DESY Workshops and TESLA TDR, ACFA Workshops and JLC Roadmap, North American LC Workshops, Snowmass2001, White, Orange,... papers.*

# World Wide Study of Physics and Detectors for Future LC

- LCWS Series of international meetings with inputs from regional studies have been vital to making the case.
- **Large group of physicists worldwide wants to build a TeV class Linear Collider starting at 0.5 TeV as the next international accelerator facility.**
- The idea endorsed by Asian, European, International - Committees for Future Accelerators, HEPAP, German Science Council, also reviewed by Global Science Forum (OECD).
- Become a signatory of the document “Understanding Matter, Energy, Space and Time: The Case for $e^+e^-$ Linear Collider”. http://www-flc.desy.de/lcsurvey/

# Physics and Detector Requirements

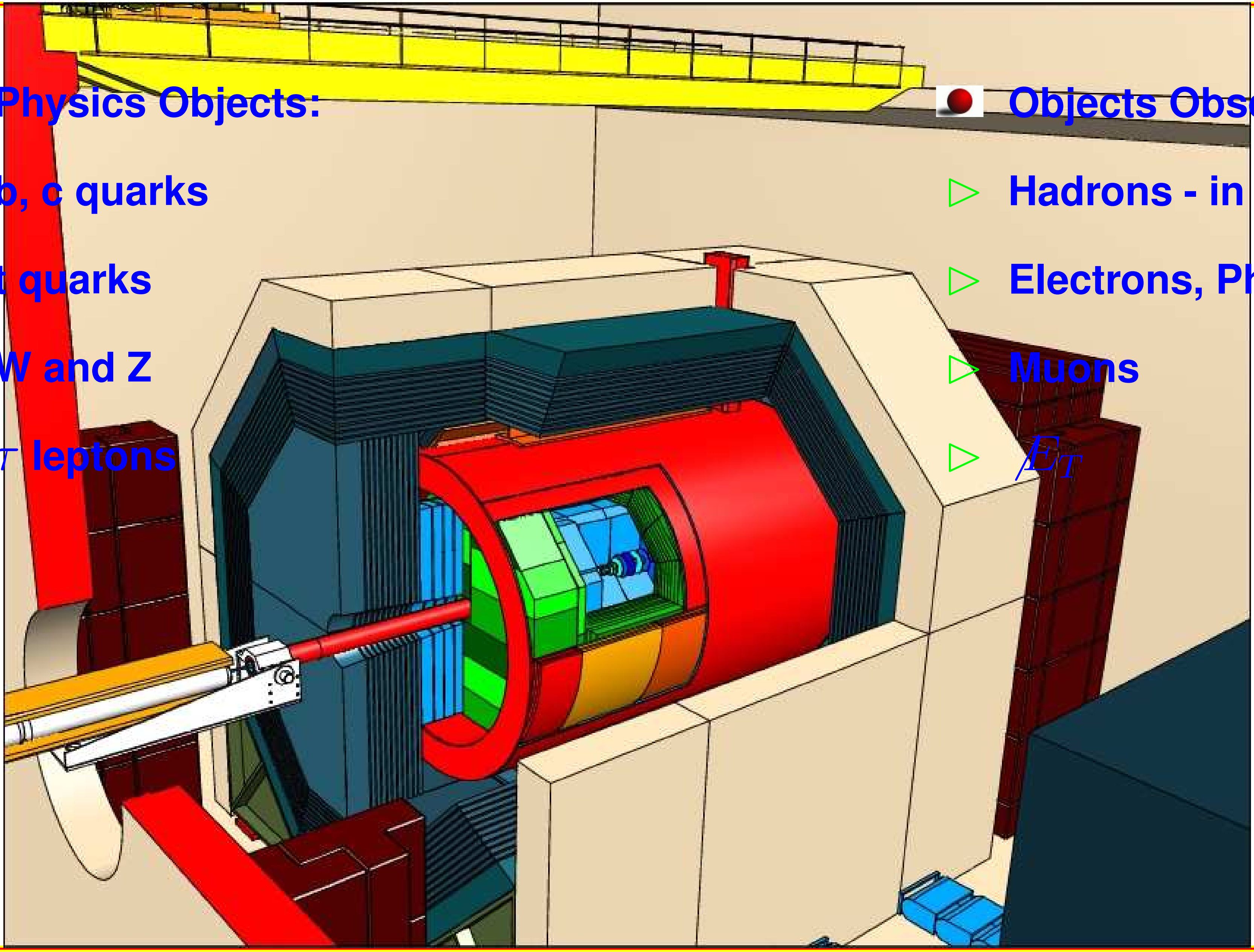
- Provide precision measurements in the energy range from $M_Z$ to 1 TeV of small signals in the presence of backgrounds.
  - ▷ EWSB - Higgs, Susy, Strong WW scattering
  - ▷ Top physics
  - ▷ New or Unknown Physics

- Two-jet mass resolution adequate for identification of W and Z
- Efficient and unambiguous heavy flavor tagging
- Momentum resolution for precision reconstruction of the recoil mass in Higgs-strahlung events (better than beam energy spread)
- Precise determination of the missing energy
- Good timing resolution to separate bunch crossings

# Detector Goals

- Many open issues for LC detectors and accelerator.
- Detector R&D devoted to the LHC helpful, but not sufficient.
- Goals of LC detector studies aim at development and optimizations in the following areas:
  - ▷ finely segmented calorimetry for particle flow measurement
  - ▷ very thin pixel vertex detector
  - ▷ integrated readout
  - ▷ development of cost reduction strategies
- Understand beamline-detector interaction
  - ▷ IR layout -masks, Final Focus
  - ▷ beam-beam interactions, Lumi spectrum, polarization, backgrounds, bunch structure

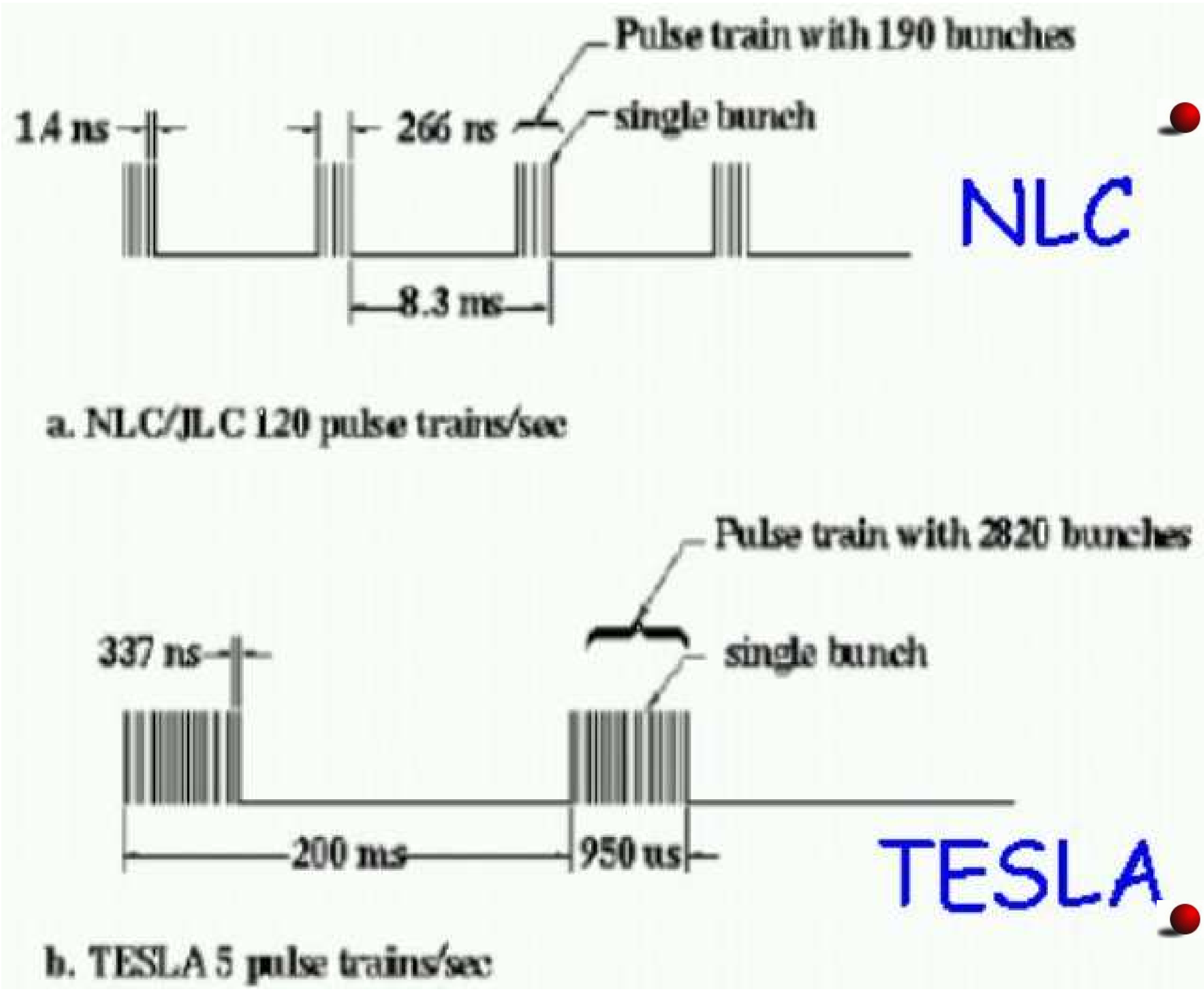
# Object Oriented Detector Design



- **Physics Objects:**
  - **b, c quarks**
  - **t quarks**
  - **W and Z**
  - $\tau$ **leptons**

- **Objects Observed**
  - **Hadrons - in Jets**
  - **Electrons, Photons**
  - **Muons**
  - $\not{E}_T$

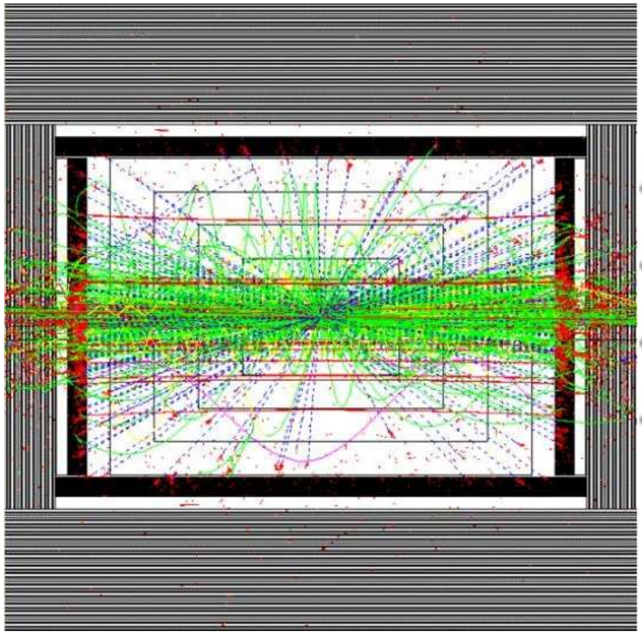
# Beam Time Structure



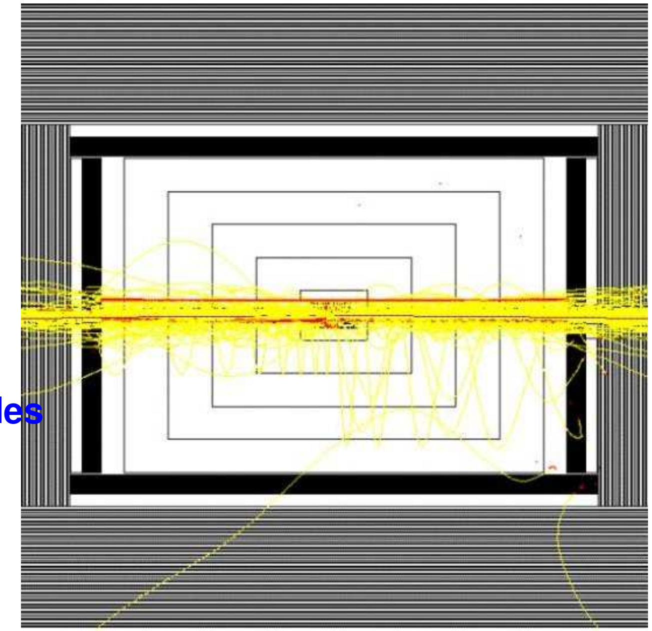

- **11.4GHz RF -warm**
- **1.3 GHz RF -cold**

# Beam Backgrounds

- **Presence of machine and physics backgrounds**
- **Physics processes w/ largest x-section give largest contribution to overlapping events**
  - ▷ **multiple interactions in single bunch (no z-spread like Tevatron)**
  - ▷ **hadrons from $\gamma\gamma$ interactions**
  - ▷ **multiple bunch collisions within the integration time of detector components**
  - ▷ **studies required to determine how to tag in time or evaluate impact on physics analyzes.**

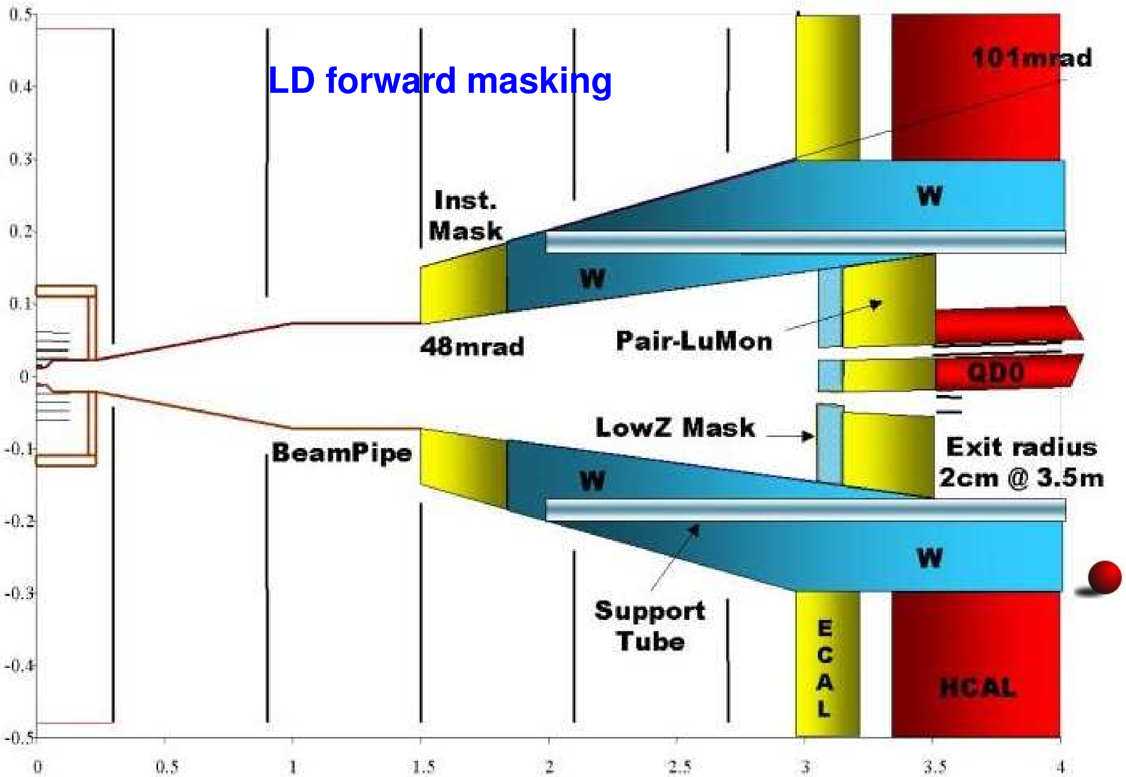


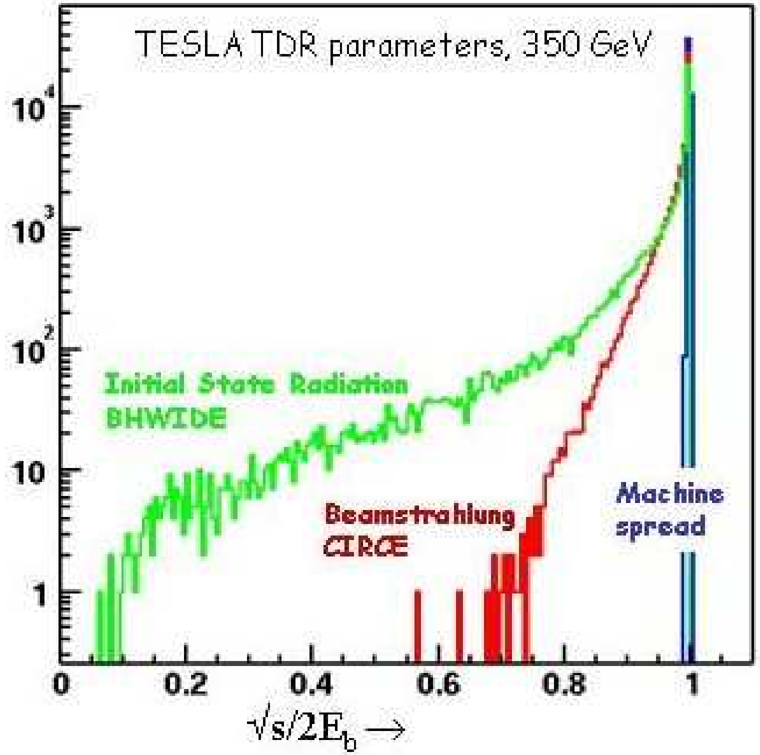
- $\simeq 150\mu\mu$ **pairs/train**
- **50 GeV/train; 24 particles**
- $\simeq 60\gamma\gamma \rightarrow hadrons$ **evts/train**
- **600 GeV/train, 100 detected particles**



# Luminosity Spectrum

- Shielding from direct and backscattered beam induced bkg;
- Provide instrumentation for luminosity spectrum measurement, hermeticity
- Combination of acollinearity of Bhabhas and beamline spectroscopy to get the full spectrum



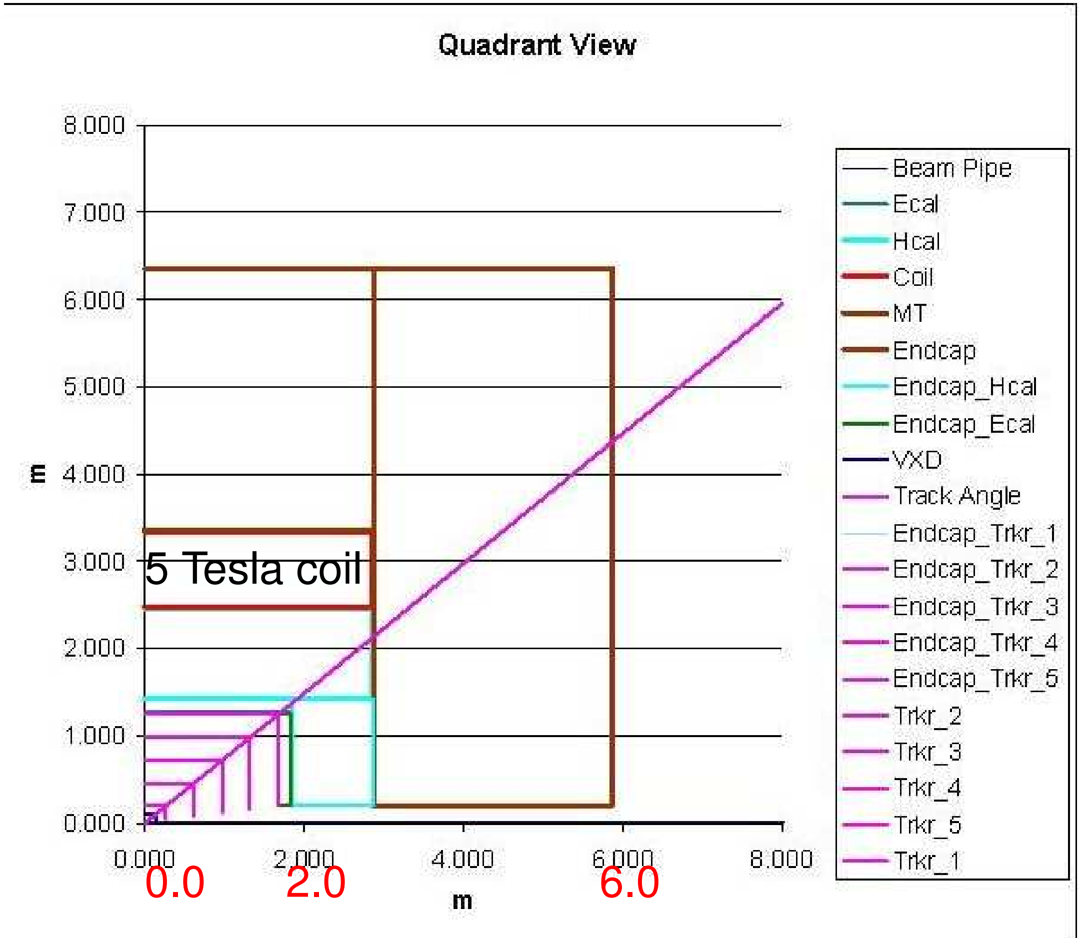



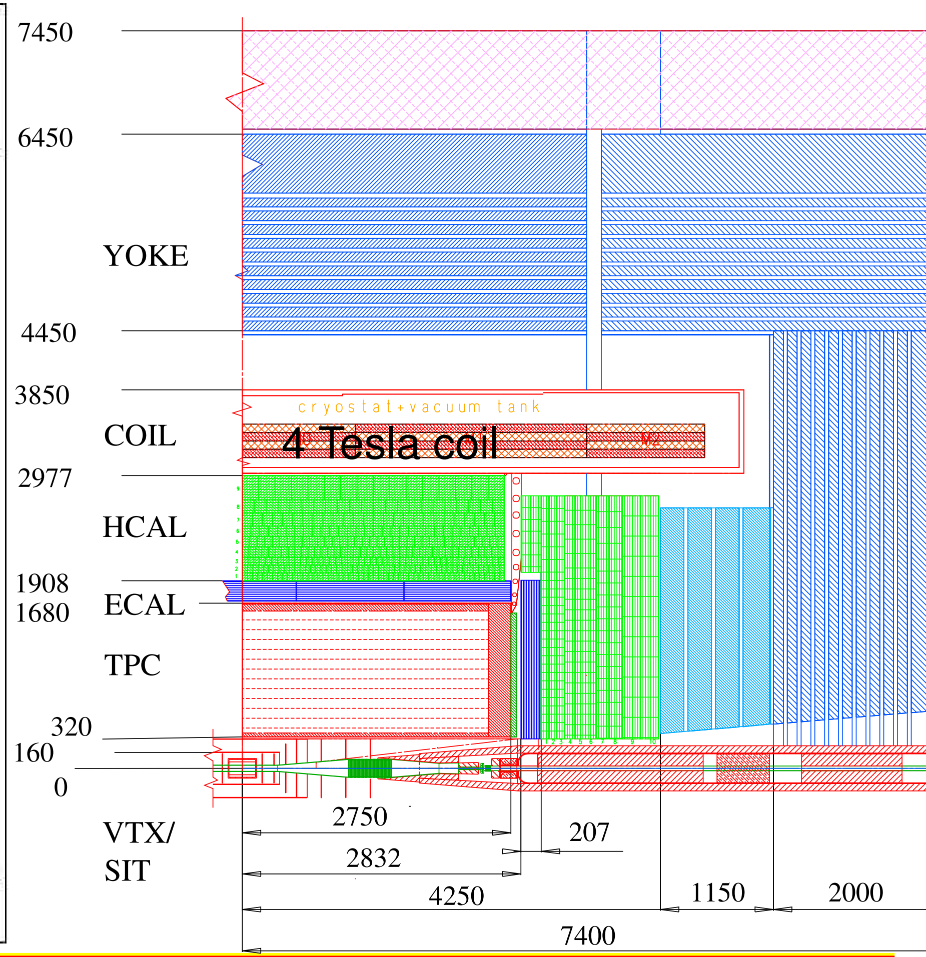

- lumi spectrum essential for precision measurements: $m_h$, $m_t$ $<$100 MeV, $m_w$, new physics

# Detector Conceptual Designs

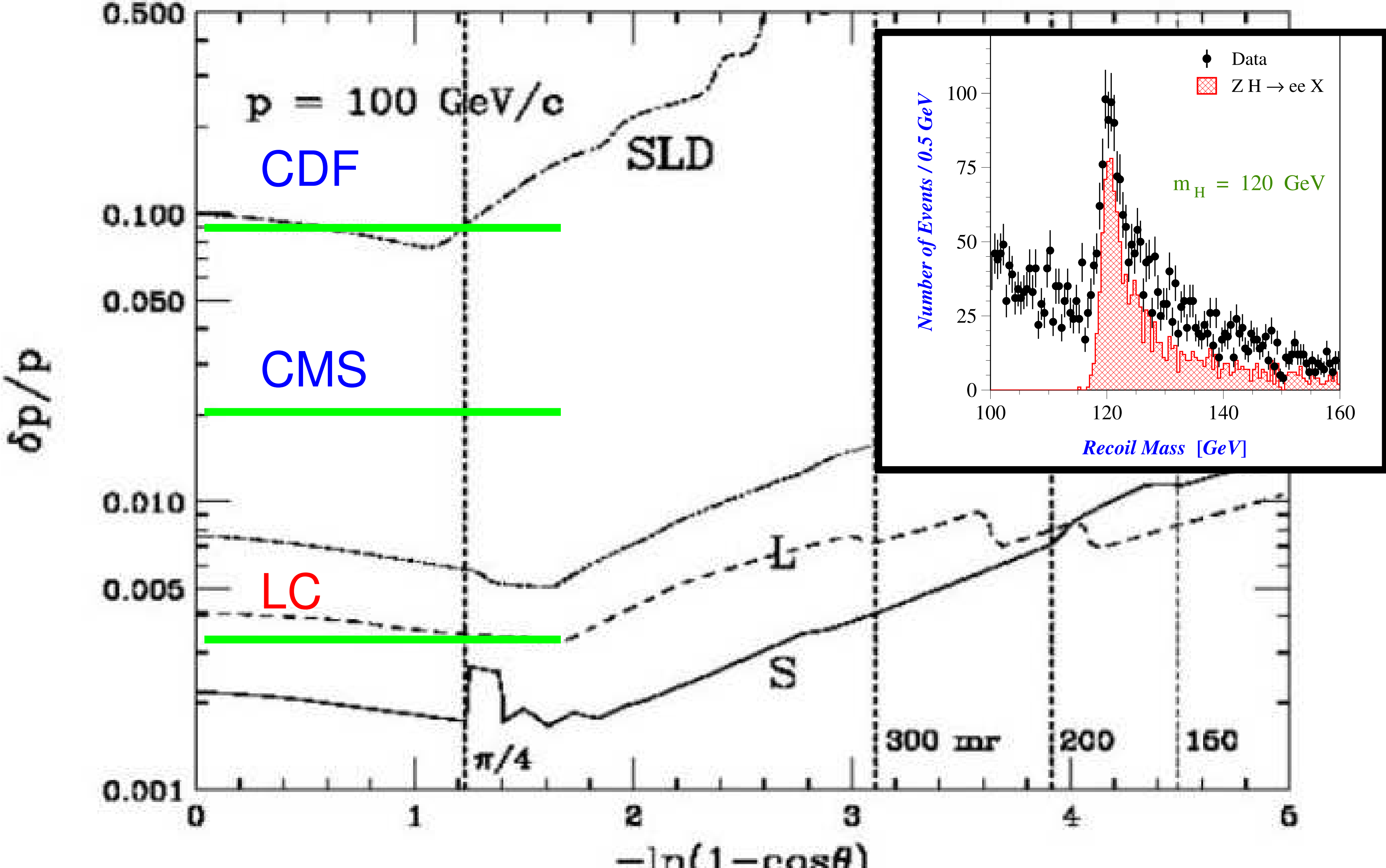
NLC SiD

TESLA LCD



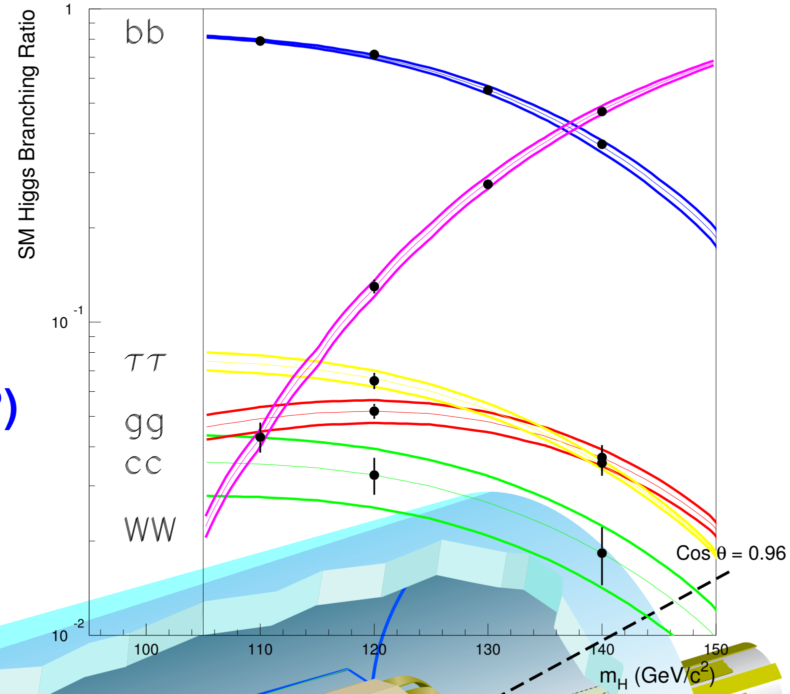



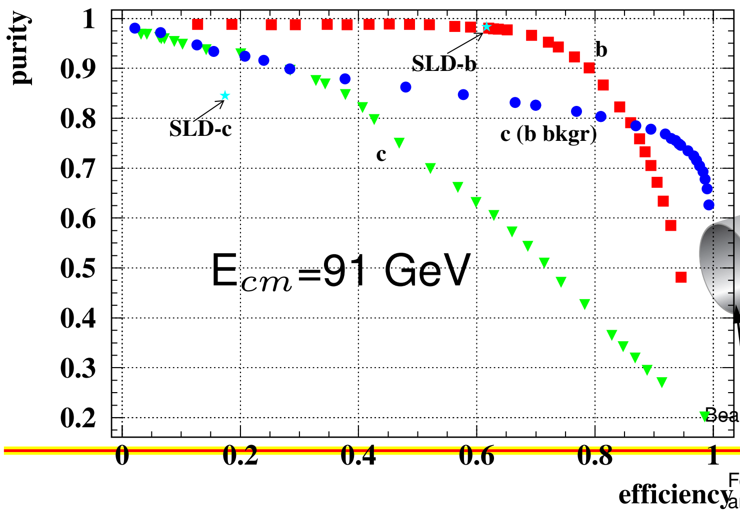
# Momentum Resolution

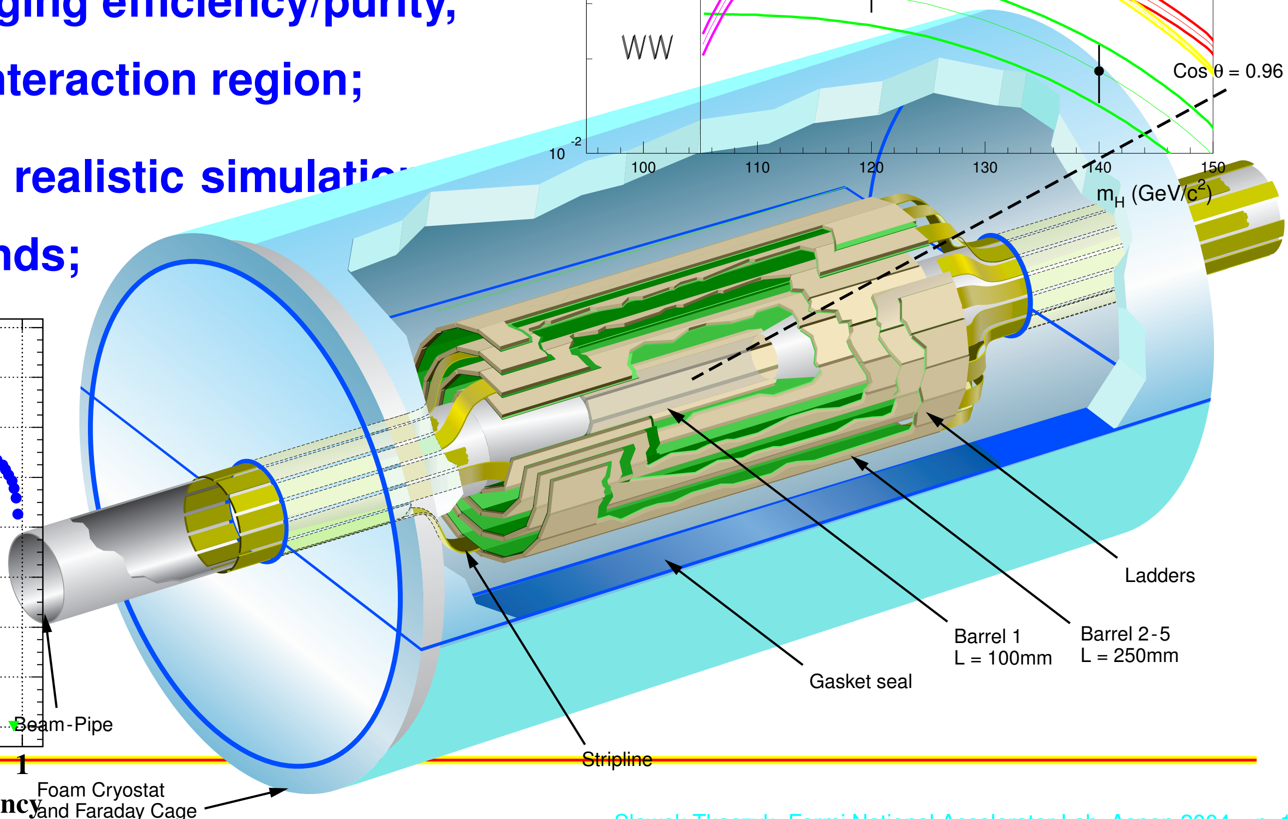


# Vertex Detection

- **Performance issues to be studied:**
  - **Optimization of the detector geometry and pixel sizes;**
  - **5-layer device for excellent pattern recognition;**
  - **Importance of the position of the Inner Layer (1cm ?) and its impact on the b,c tagging efficiency/purity, and instrumentation of the interaction region;**
  - **Higgs BR studies with more realistic simulation in the presence of backgrounds;**



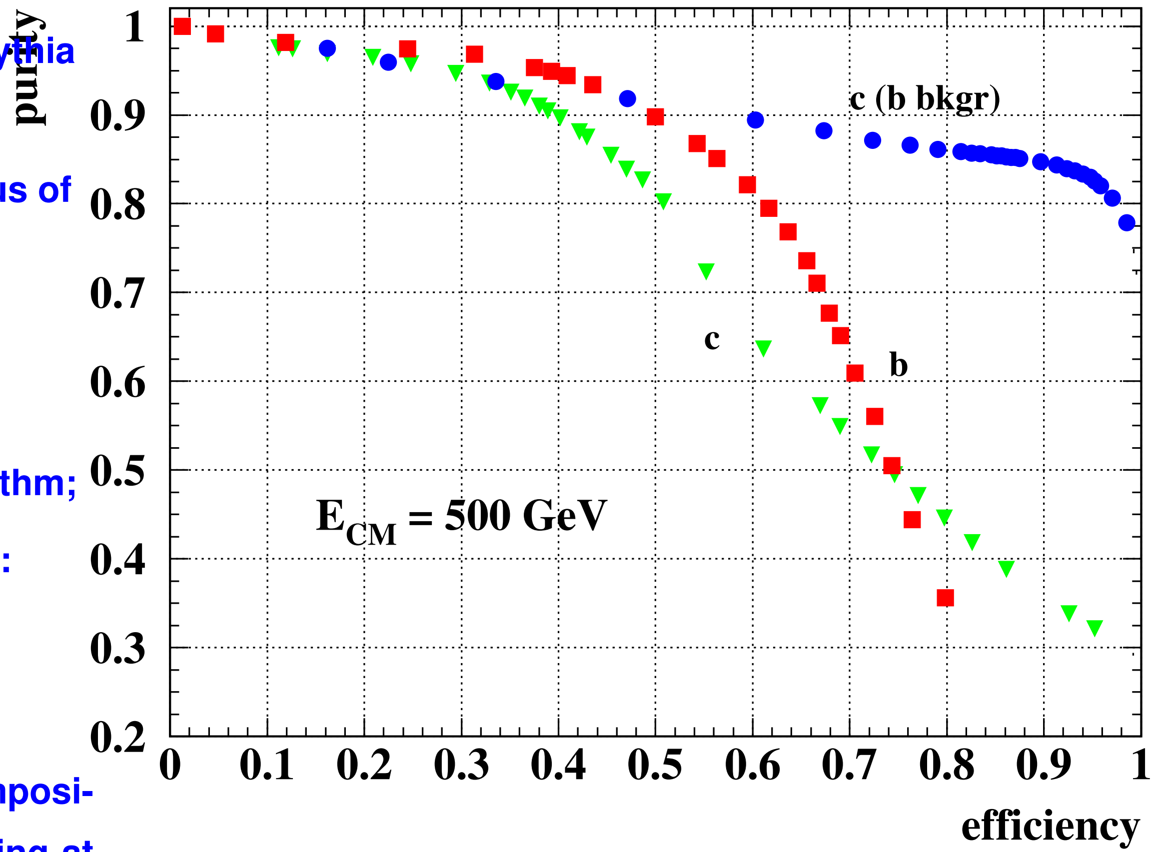



# Performance of Vertex Detector

- **Simulated tagging performance of a 5-layer CCD vertex detector,**

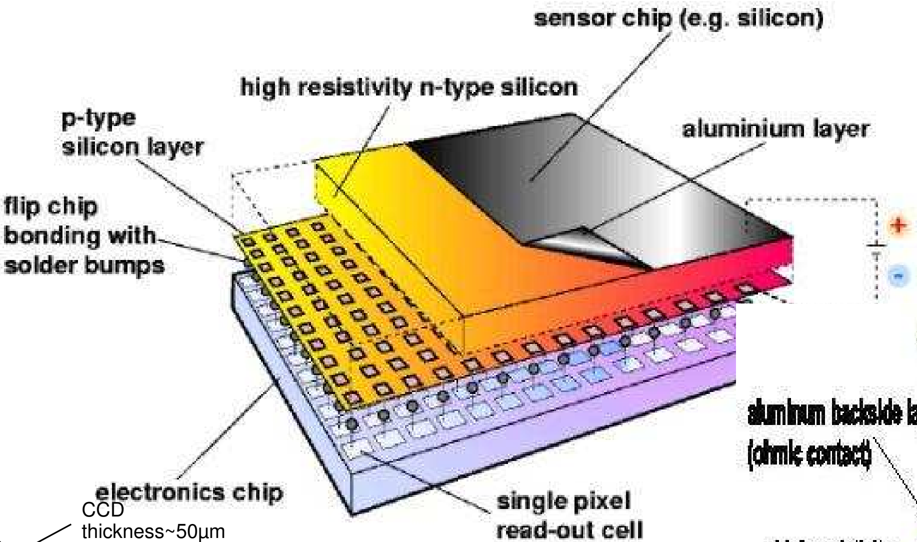
  **LC-PHSM-2003-61 C. Damerell et al.**

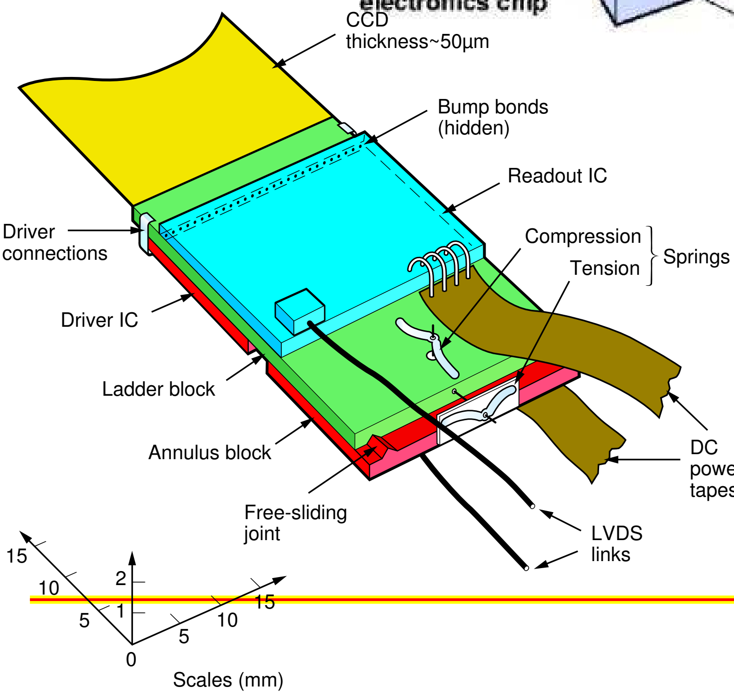
- $e^+e^- \rightarrow q\bar{q}$ process considered using Pythia at 91 and 500 GeV in a Tesla detector.
- 20 x 20 $\mu$m pixels, with first layer at a radius of 1.5cm, $\sigma_{point} \simeq 3\mu m$, $\sigma_{ip} \simeq 5\mu m$;
- simplified vertex detector geometry;
- thin ladder - 0.06%$X_0$;
- b,c flavors tagged in jets using a NN algorithm;
- Preliminary results of this simplified study:
- b-tagging worse at higher energy;
- c-tagging improved at higher energy;
- differences arise from different quark composition and increased fraction of gluon splitting at high energies;

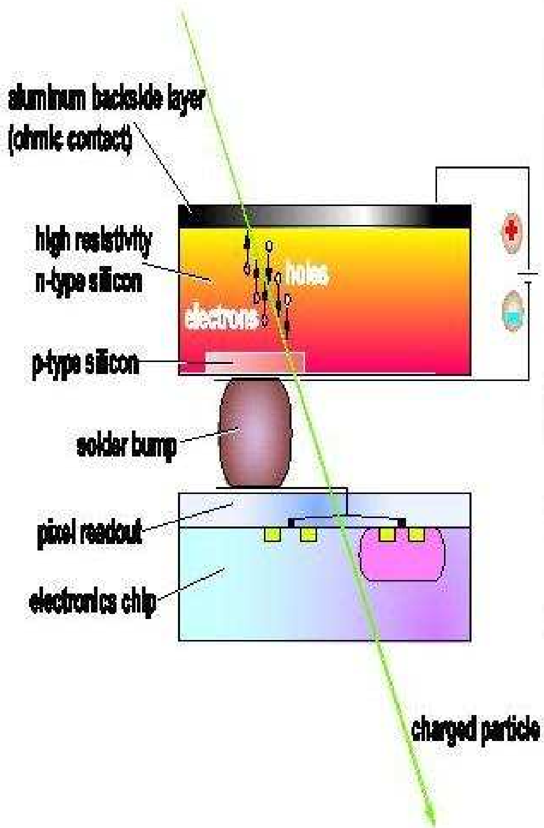


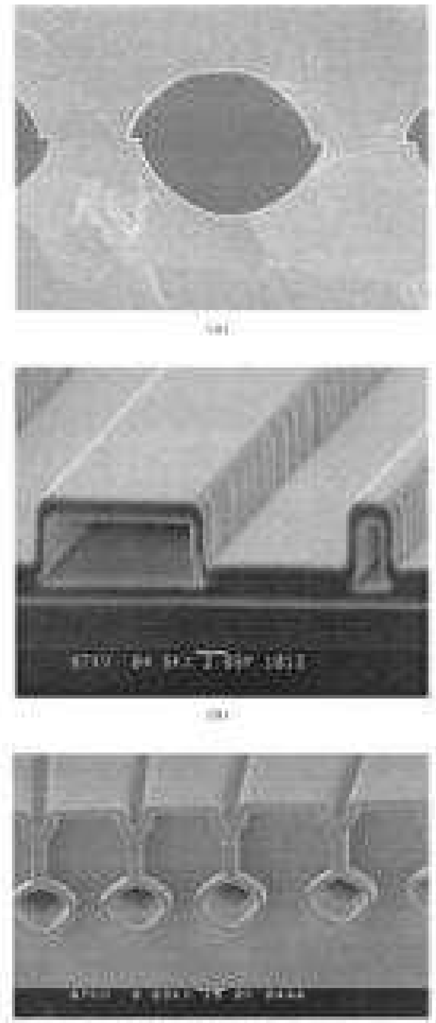
# Vertex Detection

- **Develop very thin, radiation hardened sensors, and fast readout to match the time structure of the accelerator.**



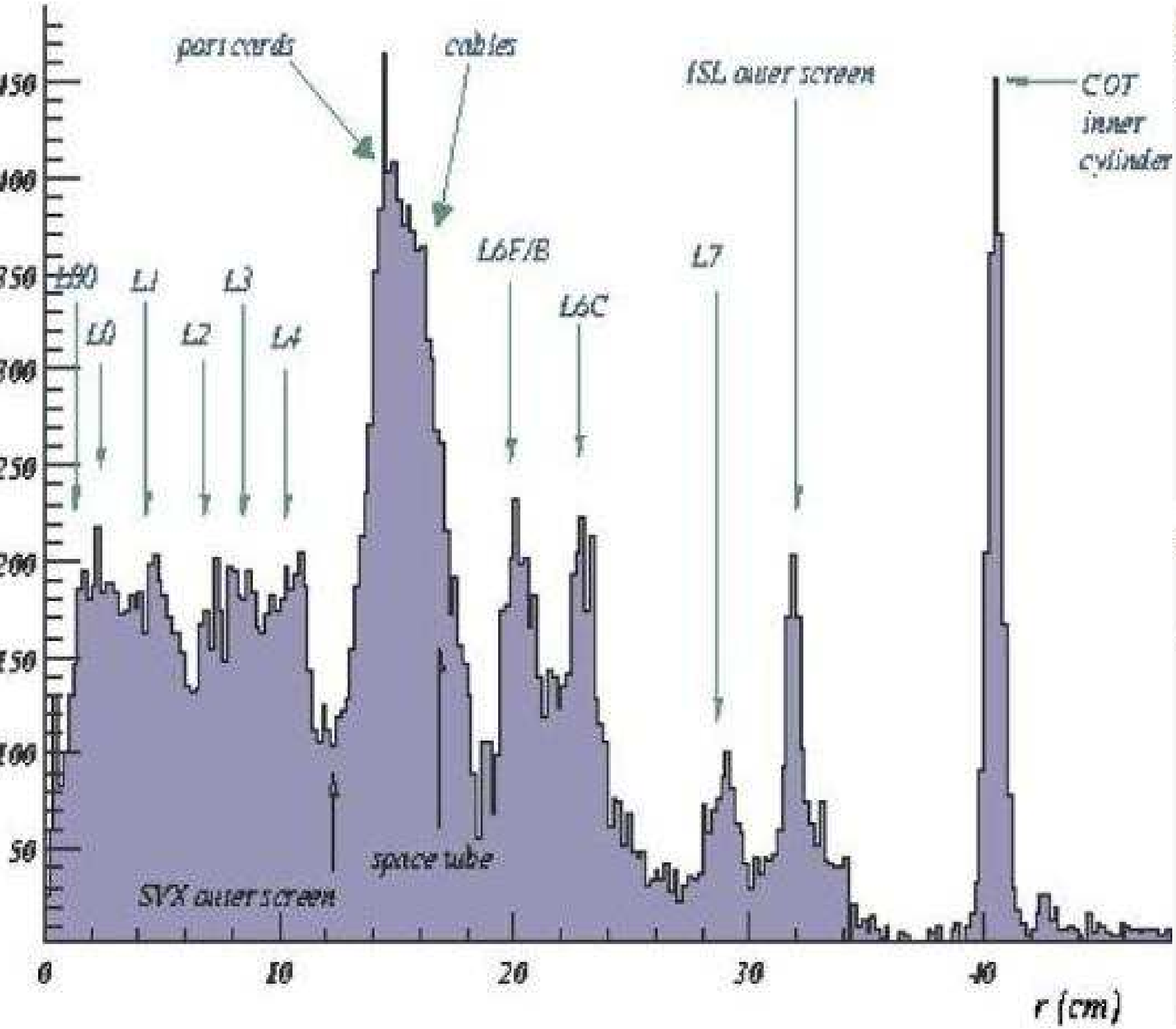



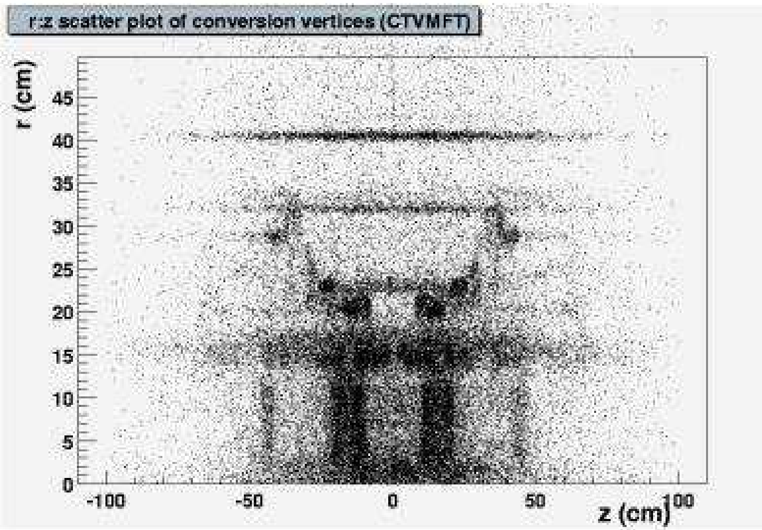



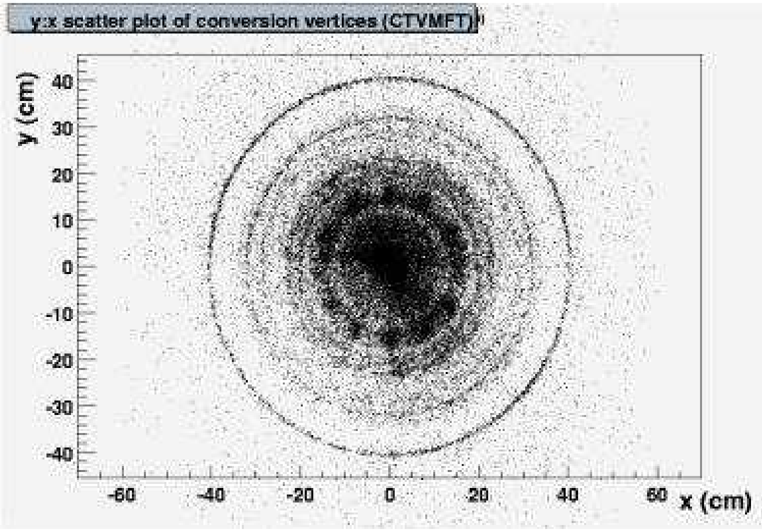



# Vertex Detection

- **What is the vertex detector mass distribution like?**



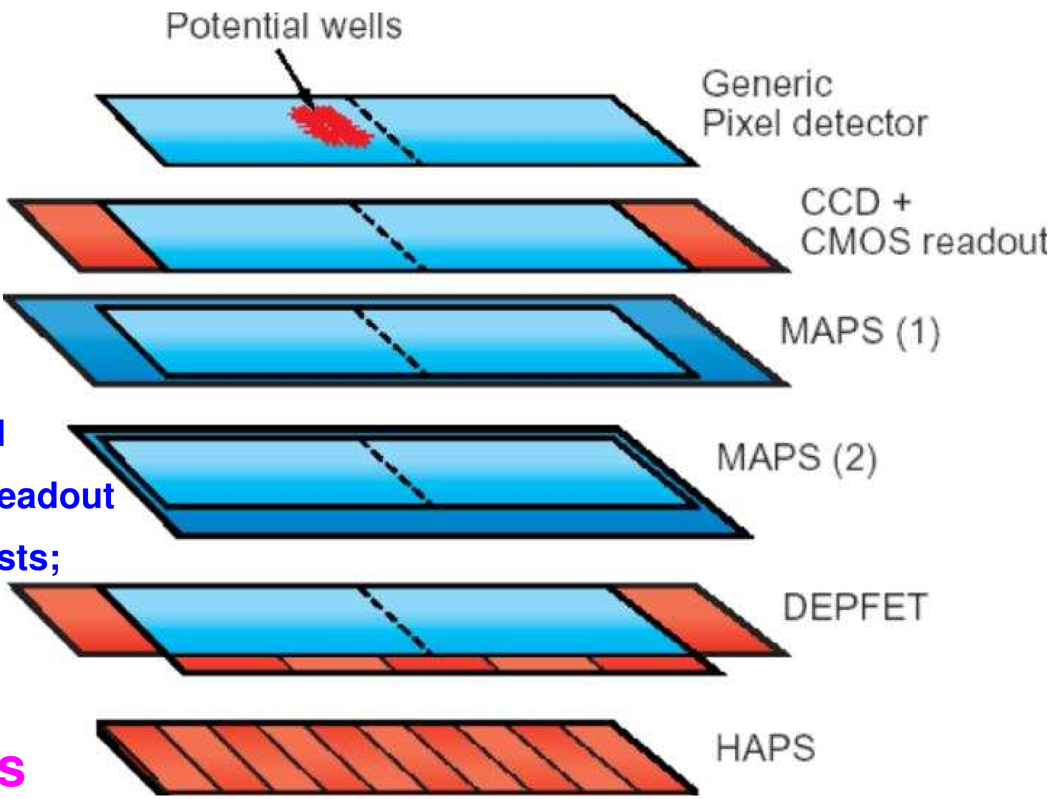



# Vertex Detection

- **Technologies for a Vertex Detector: CCD, MAPS, HAPS, DEPFET,...**

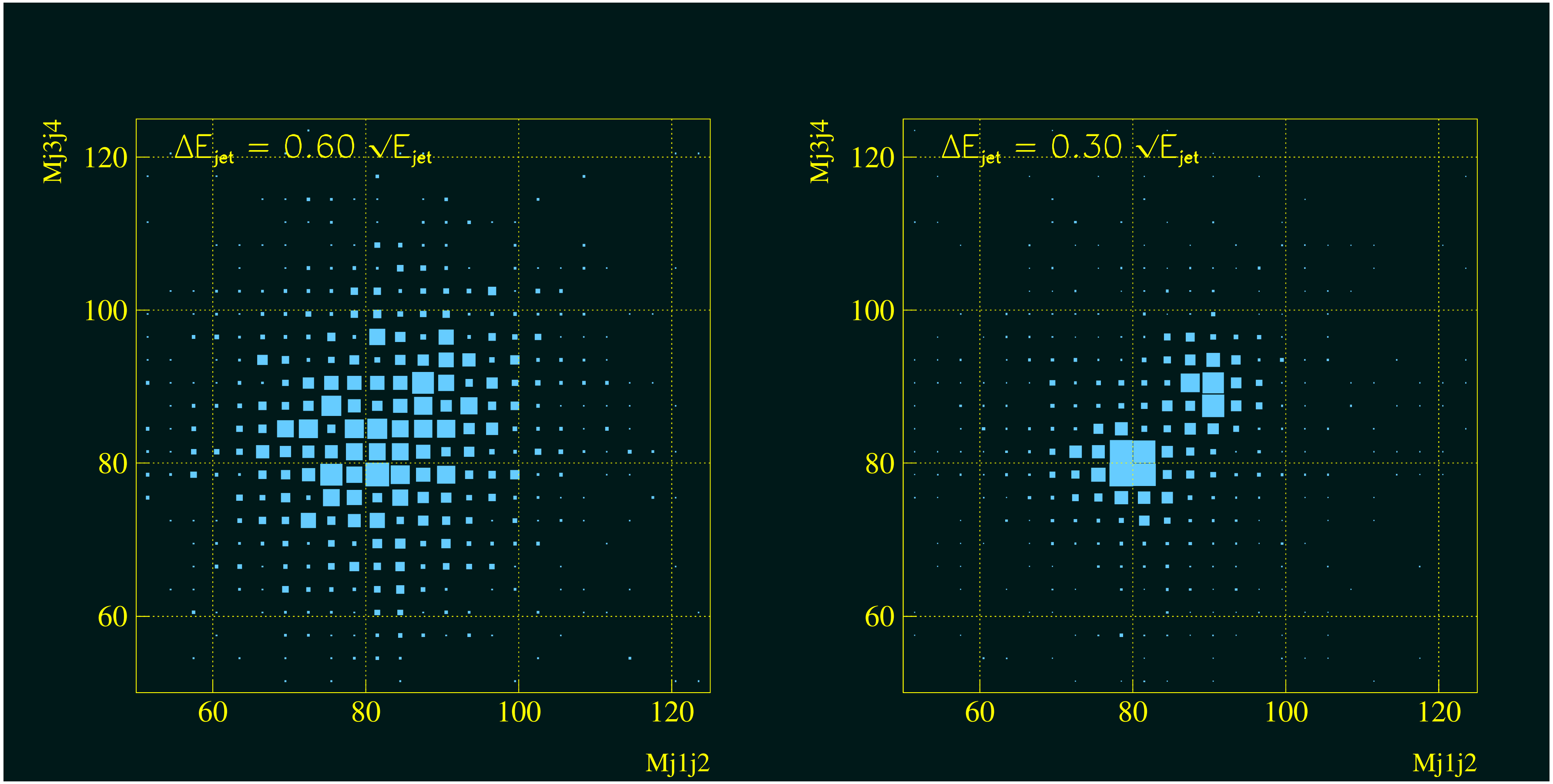
- **CCD based VTX detector**
  - **R&D to improve the limitations: readout speed, radiation tolerance, material budget;**
  - **development of fast column parallel CCD with readout electronics, 50 MHz;**
  - **thin ladder - unsupported version - 0.06%$X_0$- problematic; or semi/fully supported versions 0.1%$X_0$ under study;**
- **Monolithic Active Pixel Sensor (CMOS) - small prototypes (MIMOSA-n) with column parallel readout and zero suppression fabricated and under tests;**
- **DEPFET - first structures under tests**
- **For all options there is much scope for development, but it is important to push hard for the immense physics prizes.**




C. Damerell

# Calorimeter Performance Goal

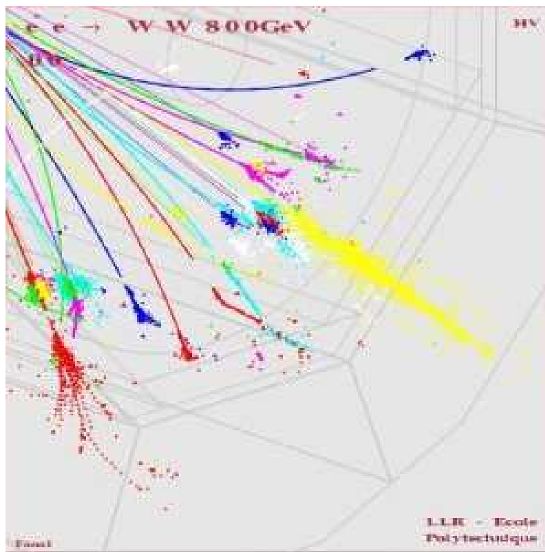
- **Precision measurement of jet energy to separate Ws and Zs in hadronic decays on an event by event basis:**
  $e^+e^- \rightarrow \nu\bar{\nu}WW(ZZ)$, $e^+e^- \rightarrow HHZ$



# Calorimetry

- Energy of isolated charged calorimeter cluster may be replaced by better measured matching tracker momentum.
- Particle flow - combination of two methods of particle energy measurement by tracker and by calorimeter, since charged particles in jets more precisely measured in a tracking detector.
  - ▷ for a typical multijet event: 60% charged energy; 20% photons, 10% neutral hadrons;
- Implementing Particle Flow requires separating charge from neutral energies in Imaging Calorimeter, dense, highly segmented in 3D calorimeter with $\sigma_E/E \sim 30\%/\sqrt{E_{jet}}$ or better.

- The main lines of design:
  - ▷ minimal re-interactions, separate particles in the tracker;
  - ▷ dense material for compact showers;
  - ▷ granular and hermetic calorimeter at large distances
- Active interplay between simulation and detector designs.

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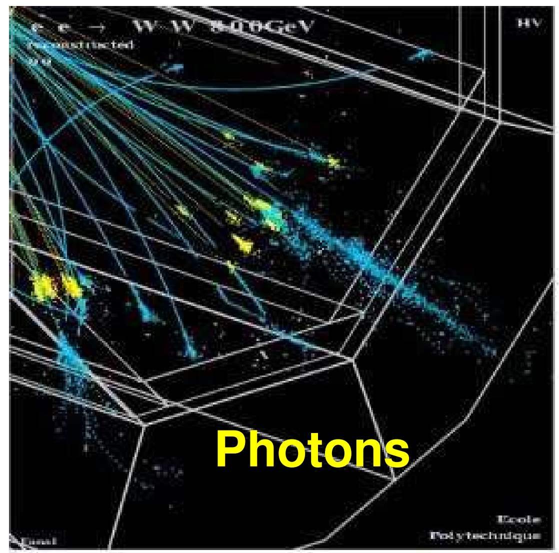



reconstructed

# Calorimeter R&D

- Many calorimeter R&D efforts ongoing or being planned worldwide: CALICE,...
- Current thinking will guide the future calorimeter designs:
  - ▷ new ideas, designs, technologies possible;
  - ▷ development of new reconstruction algorithms;
  - ▷ optimization of designs.
- The future implementation of calorimeters will also depend on the designs and performance of other detector subsystems (tracking...).

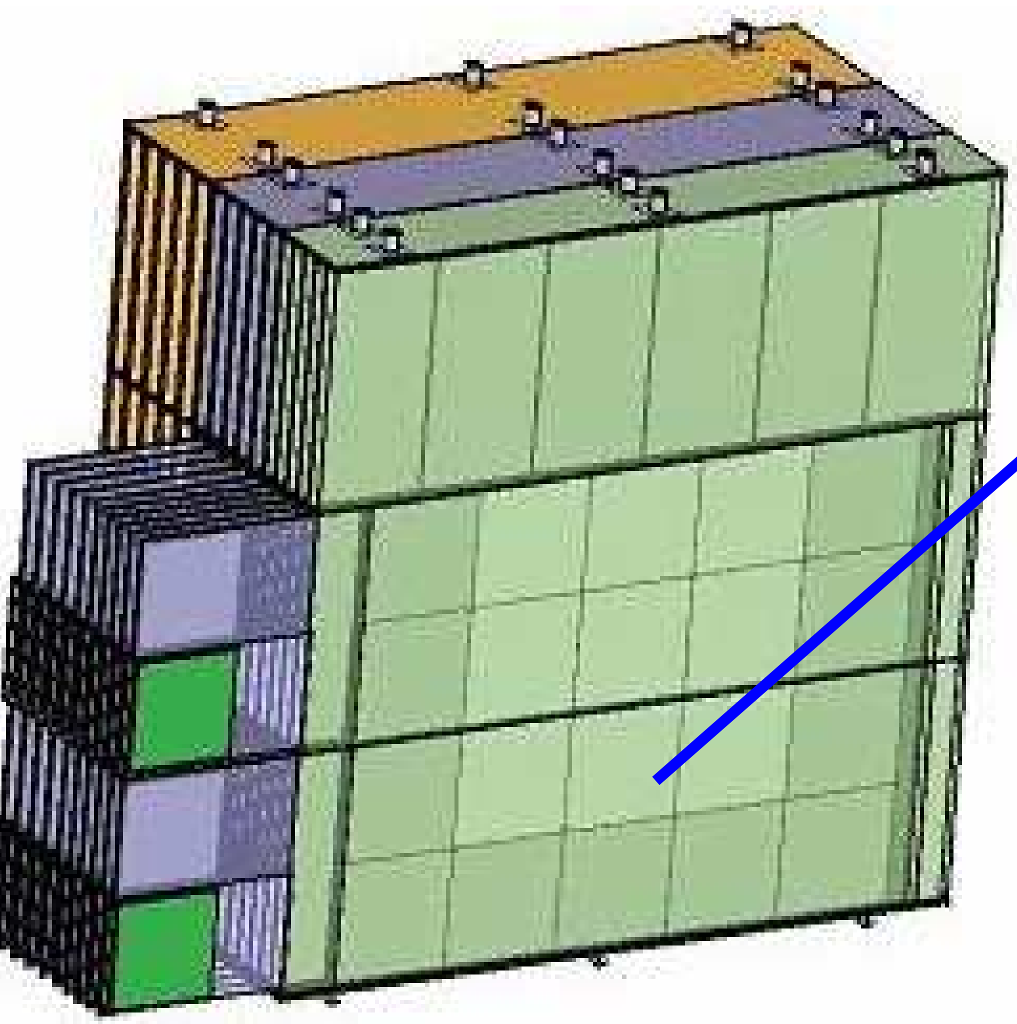
# Calorimeter Technology Options

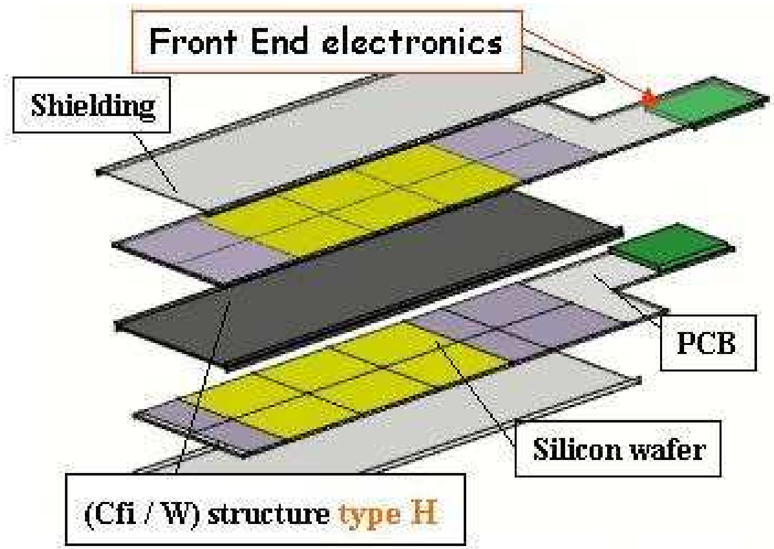
- **Electromagnetic-ECAL**
  - ▷ **Silicon-Tungsten;**
  - ▷ **Crystal $PbWO_4$;**
  - ▷ **Silicon-Scintillator**
- **Hadronic - HCAL**
  - **Analog Readout:**
    - ▷ **Tiles**
  - **Digital Readout:**
    - ▷ **Gas Electron Multipliers -GEM**
    - ▷ **Resistive Plate Chamber -RPC**
    - ▷ **Scintillator**
    - ▷ **Short Drift Tubes -SDT**

Recent summary by A. White at Jan'04 ALCPG at SLAC

# ECAL Prototype R&D

- Silicon-Tungsten 40-layer sandwich, 1 x 1cm$^2$ pads; matched to EM shower size;
- Simulated resolution: $\sigma_E/E = 0.11/\sqrt{E(GeV)}$

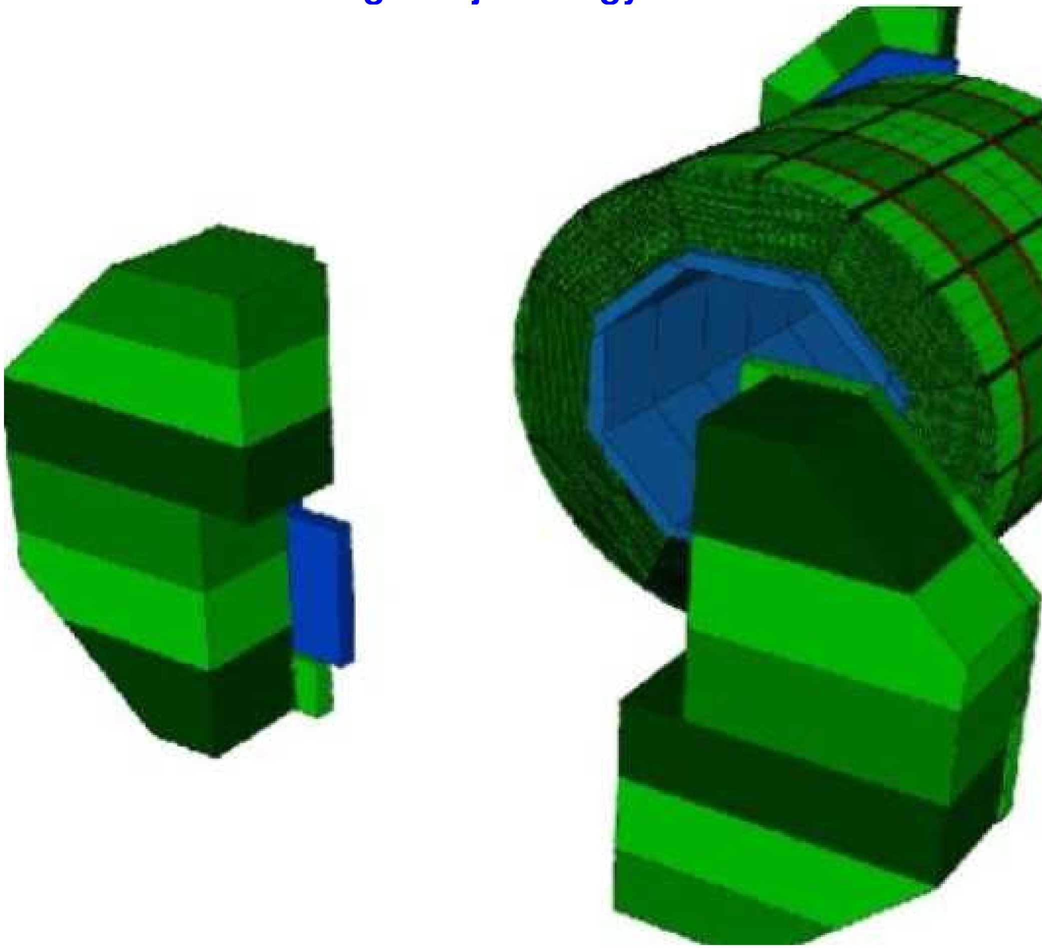


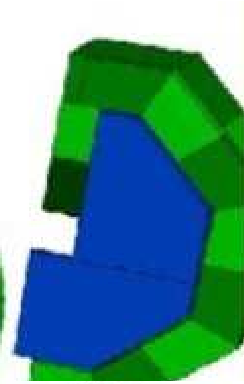


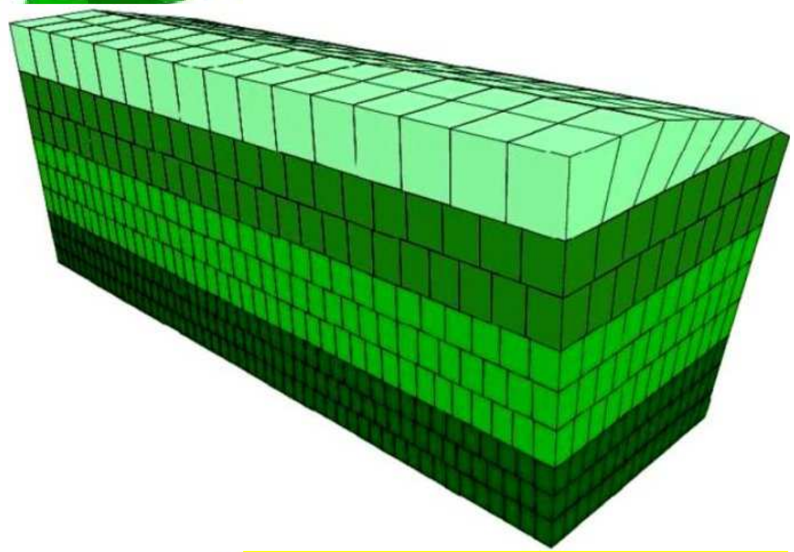
# HCAL Prototype R&D

- Physics requirements emphasize segmentation/granularity, transverse and longitudinal, over intrinsic energy resolution.
  - segmentation to allow for efficient charged particle tracking
  - intrinsic energy resolution for single neutral hadrons need not to degrade jet energy resolution

- HCAL located inside coil
- Thickness: $> 4\lambda$
- Two readout options:
  - Analog readout: scintillator tiles;
  - Digital readout: RPC, GEM,..
- Cell structure:
  - Passive medium:2cm
  - Active medium:1cm



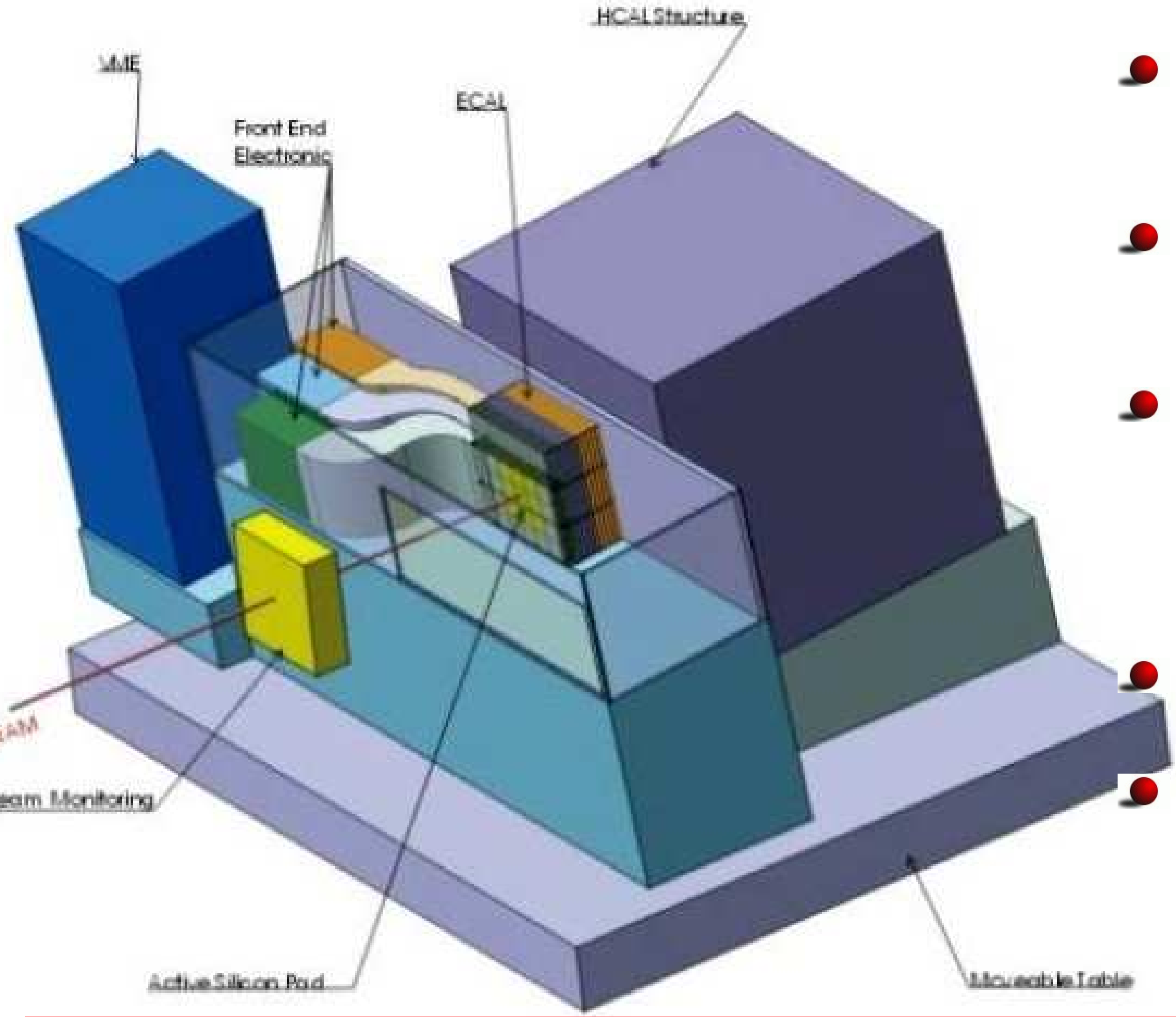




# Calorimeter

- How to test the Particle Flow or what drives the choice of a detector design?
- Physics limitations, tracking resolution and shower overlaps at high energies have to be addressed.
- In ideal case, if simulation accuracy is in doubts, then build a detector, make an experiment, analyze data, redesign the detector, redo the experiment,...
- Is test beam an option?
  - ▷ Do we need jets or only different particles to validate the calorimeters?
  - ▷ can one make an equivalent of a jet in a test beam; poorly, no W's or Z's.
- Full simulation and verification with the data, or test beams are required to understand limitations to the jet energy measurements.

# CALORIMETER Prototype R&D




- Many CALO options discussed: traditional, particle flow, digital HCAL.
- Demonstration of full particle flow algorithm with pattern recognition underway.
- Extensive tests of high granularity calorimeters (data, simulations) necessary to precede any technology recommendations.
- 1m$^3$ prototype: 400,000 channels
- CALO structures in the test beam by FY06.

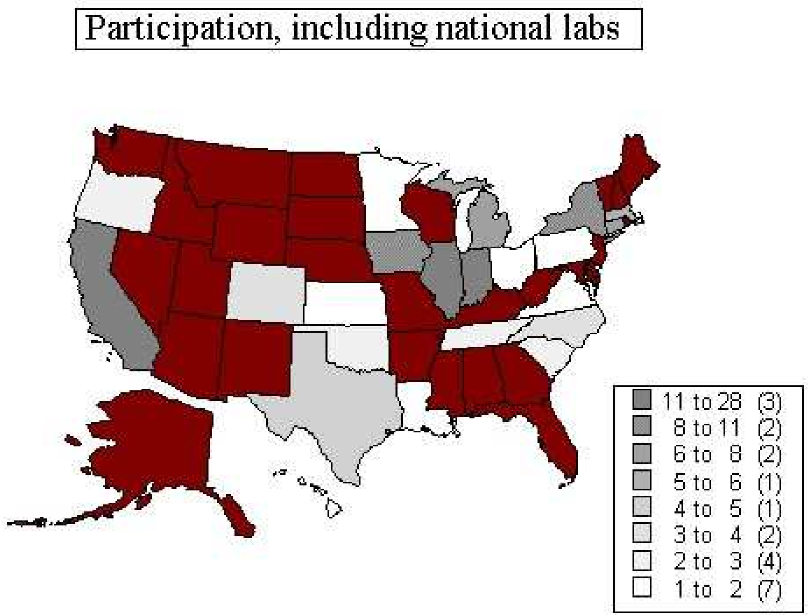
# Generic R&D

- In response to physics, technological and financial challenges new approaches must be searched for innovative accelerator and detector concepts well before they may be needed.
- Continued, diverse and vigorous R&D programs accompanied by investment are needed for near and far future projects.
- For the near future, define performance of individual detector subsystems indispensable to implement all elements of the physics program at LC, and when necessary explore new technologies in a newly launched international R&D program.
- Such R&D programs were launched in Asia, Europe and America, are coordinated internationally (J.Brau, Ch.Damerell, H.E.Fisk, Y.Fujii, R.Heuer, H.Park, K.Riles, R.Settles, H.Yamamoto - members of the panel)

*http://blueox.uoregon.edu/~lc/randd.html*

# LC R&D in the US in FY03-06

- Physicists at universities and national labs prepared a number of proposals describing a nation-wide program of R&D activities leading to the design and construction of the LC.
- University Program of Accelerator and Detector Research for the Linear Collider - a proposal written by Linear Collider R&D Working Group (DOE) and University Consortium for the LC (NSF). (Coordination by physicists at FNAL, SLAC, Cornell and Universities)
- The proposal covered both accelerator and detector projects and was prepared in coordination with other efforts world-wide to avoid unnecessary duplication of efforts.




- The groups represent a broad cross section of institutions: 71 projects, 47 universities in 22 states, 5 national labs, 11 foreign institutions.
- Lumi (9), VTX&Tracking (14), Calo (13), Muon (3).

# Conclusions

- Large, international group of enthusiastic and vibrant physicists working on the Linear Collider project.
- Linear Collider R&D efforts around the world are progressing toward affordable machine and detector designs meeting the energy, luminosity and precision goals.
- We invite you to get involved in Linear Collider R&D while the international effort ramps up. Your expertise is valuable!